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Health-risk perception and its mediating effect on protective behavioral adaptation to heat waves

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ABSTRACT

Ensuring spontaneously adjusting behaviors of the public in their daily life in response to heat waves is an important aspect of successful public health intervention under climate change. However, the current response behavior guidance released by the government is insufficient because of the limited understanding of public perceptions of heat-related risk and the motivating factors for the public's diverse adaptive behaviors. Here, we conducted a survey on the behavioral adaptations of 3065 urban residents in response to heat waves in Jinan, which is a typical city suffering from a hot climate. We provided evidence on the current state of residents' perception of heat waves and the mechanism of how risk perception mediates individual behavioral intentions upon exposure to high ambient temperatures. We found that the mediating effects of risk perception varied significantly with respect to different types of adaptive behaviors. Concern behaviors appeared be motivated completely by the mediating effects of perceived concern ($b = 0.45$, $p < 0.01$ for concerns about health guidelines; $b = 0.36$, $p < 0.01$ for concerns about the weather forecast) and severity ($b = 0.11$, $p < 0.01$ for concerns about health guidelines), while outdoor activity could be consciously adjusted according to temperature changes without those mediating effects ($p > 0.05$). Indoor cooling behaviors and transportation behaviors are partially mediated by risk perception ($b = -0.04$, $p < 0.01$; $b = 0.08$, $p < 0.01$; $b = 0.08$, $p < 0.01$ for indoor fan usage, use of air-conditioned buses, and use of private cars, respectively). The conclusions could help determine more targeted and detailed interventions to enhance public behavioral adjustments, including participation in adaption to and emergency preparedness for extreme temperature under the ongoing climate changes.

1. Introduction

Climate change has led to an increased frequency of temperature anomalies in recent decades (IPCC et al., 2007). Consequently, heat waves are increasing in number, intensity, and duration in many countries around the world and are causing adverse health impacts. Epidemiological studies in different regions have all demonstrated significant increases in heat-related mortality during local heat-wave episodes (Semenza et al., 1996; Fouillet et al., 2006; Hertel et al., 2009; China Meteorological Administration, 2014; Sun et al., 2014; Smith et al., 2015). Fortunately, heat-related health effects can be effectively avoided by adequate governmental preparation of public infrastructure, early warning systems, and protective behavioral guidelines for residents; the latter is especially important in helping laypeople protect themselves and adapt to hot weather during daily life (White-Newsome et al., 2014). Since increased extreme heat may be exacerbated by further climate change, making an action guide to advise and help the public in changing their behavioral adaptation is one of the key steps in an adaptive strategy (WHO Europe 2004). However, some previous studies have noted the inefficiency of public behavior guides due to inadequate involvement of local residents (Semenza et al., 2008a; Weinberger et al., 2018). Thus, the current guidelines may not be sufficient due to the lack of detailed information on key messages for audiences. Additionally, the guides should be made in consideration of the real demand of the lay public through risk communication, which is often ignored in policy making.

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Previous studies have demonstrated that willingness to adopt a behavioral change is influenced by multiple factors. Behavioral changes in adaptation to a risk could be motivated by increasing exposure levels as well as individual perception of risk (Wachinger et al., 2013; Ban et al., 2017; Bergstra et al., 2018). Regarding adaptive behaviors in response to climate change, studies in some developed countries have found that the association between exposure to extreme weather and individual actions may be mediated by personal perception of the risk related to extreme weather, which may promote longer-term adaptation (Semenza et al., 2008a; Spence et al., 2011; Adger et al., 2013; Demski et al., 2017). Therefore, exploring the mediating impact of risk perception on different types of adaptive behaviors may support policy makers in identifying priorities for behavioral intervention and designing targeted action guidelines according to the public's real demands regarding heat wave adaptation. However, previous studies were limited due to the inclusion of single adaptive behaviors, such as energy saving (Semenza et al., 2008b; Spence et al., 2011), and failure to examine other common daily behavioral adaptations, such as changing daily commuting routines, using indoor cooling, and engaging in concern behaviors. This limitation made it difficult to draw a complete picture of current public adaptive responses. In addition, considering the differences in weather patterns, cultural background, and degree of public communication in different countries, public perception levels may vary according to complex social factors, resulting in possible differences in the mediating effects of risk perception. Thus, it is meaningful to explore how adaptive behaviors may be motivated in developing countries in addition to developed countries. Studies relating to this topic are rare and necessary in China, a country that has suffered from extreme heat recently and is eager to mitigate and adapt to climate change (Committee of National Assessment Report on Climate Change, 2015).

This study aimed to explore the mechanism whereby urban residents adjust their behavior during local heat waves and how risk perception mediates the relationship between exposure and behavioral changes. Notably, we examined various categories of individual adaptive behaviors related to normal daily life, including concern behaviors, outdoor activity, indoor cooling behaviors, and transportation patterns. We assumed that different mediating factors would influence different behaviors. Our aim was to assess the implications of such factors to inform effective behavioral intervention and policy-making strategies for appropriate adaptation in urban areas.

2. Method

2.1. Survey description

A cross-sectional study was designed. A face-to-face questionnaire survey was conducted by professional staff at Jinan Disease Control and Prevention Center after they had been fully trained for the purpose. The survey lasted from 18th July to 6th August in 2016, which fell entirely during summer weather in Jinan. Jinan City is located in eastern China, which experiences frequent impacts from climatic disasters due to a rapid temperature increase occurring since the 1980s (China Meteorological Administration, 2014). The high population density, massive urbanization, and hot weather in the summer lead to an increased possibility of negative heat-related health impacts in Jinan (Zhang et al., 2016). Due to data availability, Jinan is an appropriate site to be surveyed. During the survey period, unusually hot days (days with a daily average temperature greater than the 97.5th percentile during 2013–2016) continuously occurred (Fig. S1).

A three-stage sampling process was applied: first, communities with more than 10,000 residents were randomly selected in three urban districts of Jinan City; second, residence buildings were selected within the community using a simple random sampling method; third, cluster sampling was applied to all households of the selected buildings. Residents who were over 16 years old and had lived in the city for at least one year were interviewed. If no eligible individuals resided in the household, then another building was randomly selected from the pool of buildings in the community to identify potential participants. Structured surveys were conducted with each participant, all of whom were told about the survey objectives and provided written informed consent.

Data quality control was applied in two stages. During the survey stage (1) at least 1000 residents were required to be surveyed in each community, and 90% of their questionnaires must have been collected; (2) for each questionnaire, the interviewers were asked to verify the degree of completion and the existence of logical errors for all mandatory questions; (3) after the investigation was completed, 5% of the finished questionnaires were reviewed, and the compliance rate was required to be greater than 95%. During data processing stage, a double-input method was applied, in which two staff members were asked use EpiData software to input the survey data, which were compared for consistency. Inconsistent records were corrected, and unclear records due to hand writing were returned to the interviewers.

2.2. The questionnaire

The questionnaire consisted of three parts: demographic and socioeconomic information, perception of heat-related health risk, and behavior changes to cope with local heat waves. The perception part of the questionnaire was designed based on a psychological paradigm method regarding natural hazards (Slovic, 1987; Wachinger et al., 2013). Using questionnaires to obtain scaled answers to describe their perception on each feature of the hazards, the theory of the psychometric paradigm method could be used to measure the individual's subjective judgment of the risk level and whether they suffered during temperature anomalies based on their own experience, physical situation, and surrounding environment (Slovic, 1987). The perception part of the questionnaire included four questions addressing subjective concern and dread about heat-wave-related health risks and the subjectively perceived severity and controllability of those risks, details of which are listed in Table S2. These questions were designed using a 5-point scale to show different levels of an individual's subjective judgment of risk.

In the general information part, in addition to basic information such as gender, age, education year, and income, the first part also included questions concerning individual health status on the survey day (“Do you feel well or not?”) and social support (“How many people could support you if you were facing problems?”).

The behavior part consisted of twelve questions about how individuals changed their behaviors during heat waves. Four categories of behavior were considered in this section: (1) concern behaviors, including concern about weather forecasts and health protection guidelines; (2) outdoor activities, including the duration and intensity of the participants’ activities outside; (3) indoor cooling behavior, including the usage of fans and air conditioners; and (4) transport patterns, including transportation fully exposed to ambient high temperature (walking or riding a bicycle) versus transportation that offers protection from the heat, such as taking a bus, driving a private car, or taking a taxi. A four-point scale (Table S3) was applied to measure behavioral changes during heat waves (4 = “I increase the behavior”, 3 = “I do not change the behavior”, 2 = “I reduce the behavior”, 1 = “I never do it regardless of heat wave”).

2.3. Temperature exposure

Daily temperature was adopted as the exposure factor for the purpose of determining the impact of ambient temperature changes on an individual's behavioral response. This information may provide a chance to examine how individuals react to abnormal temperature during daily life, in the context of mostly normal temperatures, in a broader background. The timing of the survey during ongoing hot

Table 1
Detailed information on behavioral changes during heat waves.

Category of behaviors	Detail behaviors	Never do it	Behavior change	Behavior change status N (Percentage)		
		(N)	(N)	Increase	Remain unchanged	Reduce
Concern behaviors	Care about the weather forecast	207	2831	1707(60.3%)	1099(38.8%)	25(0.9%)
	Care about health protection guidelines	400	2625	1466(55.8%)	1146(43.7%)	13(0.5%)
Outdoor activity behaviors	Duration of outdoor activity	89	2959	77(2.6%)	429(14.5%)	2453(82.9%)
	Intensity of outdoor activity	97	2951	23(0.8%)	376(12.7%)	2552(86.5%)
Indoor cooling behavior	Use of indoor air condition	384	2658	2354(88.6%)	243(9.1%)	61(2.3%)
	Use of indoor fan	65	2979	2524(84.7%)	279(9.4%)	176(5.9%)
Transportation behaviors	Walk	217	2789	36(1.3%)	553(19.8%)	2200(78.9%)
	Bike	999	2009	61(3.0%)	605(30.1%)	1343(66.9%)
	Ordinary bus	528	2476	307(12.4%)	796(32.1%)	1373(55.5%)
	Air conditioning bus	567	2423	1285(53.0%)	676(27.9%)	462(19.1%)
	Car	700	2305	1182(51.3%)	829(35.9%)	294(12.8%)
	Taxi	1088	1904	584(30.7%)	961(50.5%)	359(18.8%)

weather may be helpful to accurately measure perceptions and memories of extreme heat (Ban et al., 2017).

Daily average temperature and relative humidity data during the period from July 18 to August 6, 2016, according to a monitoring station (No. 548230) located nearest to the survey sites, were downloaded from the Chinese meteorological data sharing website to serve as the exposure factor data. The meteorological data were matched to each individual according to the survey date. Consequently, each participant had an individual temperature exposure level.

2.4. Statistical analysis

A descriptive statistical analysis was conducted to show changes in each category of adaptive behaviors (Table 1). Multiple mediation analysis, which is commonly used in the behavioral sciences (Preacher and Hayes), was applied to examine the mediating effect of multiple heat-related risks perceptions (perceived concern, dread, severity, and controllability) on the associations between temperature exposure and adaptive behaviors. The direct effect of temperature on behavior changes and the indirect effects of perception on behavior changes were both considered, and the latter could indicate the mediators of the path from exposure to behavioral response. The daily average temperature and relative humidity were input into the model as exposure factors. Additionally, considering the potential socio-economic impacts on perception or behavioral changes, multiple relative covariates, including the demographic factors of age, gender, education, income, as well as other socioeconomic factors of health status and social support, were included in the model to control for their influence. The variables are presented in Table S4. Thus, the results presented here have been adjusted for those covariates. Importantly, in the mediation effect analysis, we excluded all responses of "1 = I never do it" for each behavior to avoid a potential confounding impact on the results. Furthermore, a cross table was created to present how residents adjusted their transportation patterns when they reduced the use of transportation that totally exposed them to the hot weather (Table S5).

Multiple mediation analysis was conducted by the PROCESS procedure version 3.0 within SPSS 21.0, developed by Preacher and Hayes (Hayes, 2017). The significance levels of mediating effects from perception factors were determined by bootstrap confidence intervals (0.95) with 5000 bootstrap samples. $p < 0.05$ was applied as the significance threshold. The figures in the manuscript were produced using Visio software.

3. Results

Of 3082 residents interviewed, 3065 valid responses were obtained due to the exclusion of a few missing values for demographic information, resulting in an effective response rate of 99.4%. The sample structure is presented in Table S1. The sample consisted of 49.6% males and 50.4% females, with 52.0% younger than 45 years of age, 61.4% having only a primary education, and 52.8% of respondents were at a middle income level. Table S1 shows the consistency between the structure of the sample population and the city population, which indicates that no noticeable sampling bias existed.

Scores for each perception question are presented in Table S2. Respondents in the studied area had mean scores of 3.35, 3.21, and 3.17 for perceived concern, dread, and severity of the heat-wave-related health risk, respectively. Scores above the median value of 3 suggested a high perceived level of the variable. The mean score of perceived controllability of health risk was 2.91, which was below the median value of 3.

Behavior adaptations to heat waves are presented in Table 1. The responses were classified into "I never do it" regardless of heat waves and "my behavior changed" during heat waves, including "I increased my behavior","I maintained my behavior", and "I reduced my behavior". In the urban area, more than half of the respondents reported increased concern about the weather forecast (60.3%) and health protection guidelines (55.8%); similarly, over 80% of the respondents increased indoor cooling behaviors (88.6% for air conditioners and 84.7% for fans) to adapt to heat waves. In contrast to indoor cooling behaviors, the respondents sharply reduced outdoor activities, including an 82.9% reduction in duration and an 86.5% reduction in intensity. Different changes occurred for different modes of transportation: respondents reduced walking (66.9%) and cycling (55.5%), which are the modes that directly expose the user to high ambient temperatures; meanwhile, respondents increased the use of transit that protects riders from direct exposure, such as air-conditioned buses (53.0%) and private cars (51.3%). Some behavior remained unchanged, such as taking a taxi (50.5%).

Temperature exposure (the independent variable) was significantly associated with the perceived factors, including perceived concern, dread, severity, and controllability (the mediating variables), and was also significantly associated with intentions to change behavior in some cases (Figs. 1–3). Multiple mediation analysis indicated that the perceived factors had significant influences on behavioral changes. Notably, the mediating effects were different for different behaviors. For concern behavior (presented in Fig. 1), perceived concern strongly impacted the increase in caring about health protection guidelines ($b_{guidelines} = 0.45$, $p < 0.01$) and the weather forecast ($b_{forecast} = 0.36$, $p < 0.01$). Without the mediating effect of perceived concern, exposure to temperature has only minor effects on concern behaviors ($p > 0.05$). For outdoor activities and indoor cooling behaviors, direct and indirect effects existed at the same time (Fig. 2). Perceived concern was significantly associated with the reduction of intensity ($b_{intensity} = -0.04$, $p < 0.01$) and duration ($b_{duration} = -0.02$, $p < 0.05$) of outdoor activity. The direct effects of exposure on outdoor behavioral changes

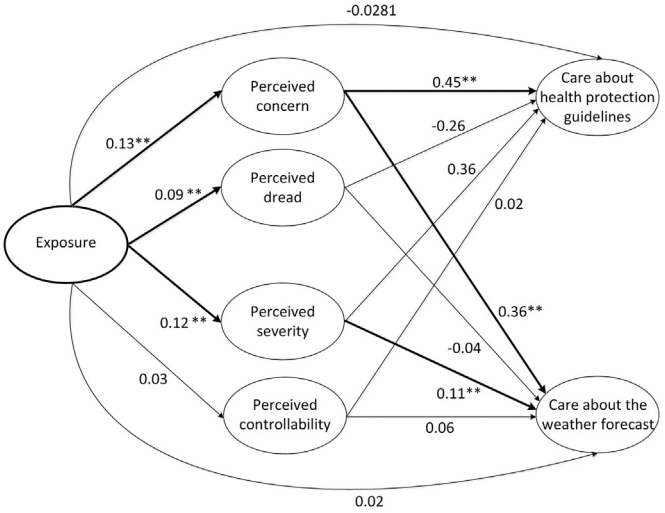

Fig. 1. Changes in concern behavior as a heat-wave adaptation mediated by public perceptions of concern, dread, severity and controllability related to heat-related health risks. Bold lines indicate significant effects (**p < 0.01, *p < 0.05).

were significant (p < 0.01). Similar results were observed in indoor cooling behavior changes, in which exposure to high temperature could directly influence the usage of air conditioners and fans, as well as indirectly impact the behavioral adaptation through mediation by perceptual factors. As the temperature increased, the use of transportation directly exposed to the heat was reduced significantly (b_{walk} = -0.08, b_{bike} = -0.11, p < 0.01), with a weak mediating effect (Fig. 3), while temperature exposure could influence the change in protective transportation patterns, such as taking air-conditioned buses and driving private cars, through significant mediating effects of perceived concern ($b_{AC\ bus}$ = 0.08, b_{car} = 0.08, p < 0.01), dread ($b_{AC\ bus}$ = 0.1, p < 0.01), and severity ($b_{AC\ bus}$ = 0.11, p < 0.01). A summary of the direct and indirect effects of exposure and mediators is listed in Table 2.

4. Discussion

This study used urban survey data gathered across the city of Jinan during summer to examine the impact of exposure to temperature on adaptive behavioral changes mediated by risk perception. Different behavioral adaptation options in response to heat waves were found to be completely or partly mediated by the effects of perceptual factors: individual perception of heat-related risk appeared to mediate concern behaviors completely, while perception did not present a mediating effect on outdoor activities or transportation patterns fully exposing the user to ambient heat, such as walking and cycling; perceived severity partly mediated the impacts of exposure on indoor cooling behaviors and other transportation patterns. The study results provide an initial characterization of the relationship between temperature exposure and behavioral adaptation in a Chinese urban area and may provide insight into how residents adapt to local temperature anomalies on their own during climate change.

High levels of perceived concern, dread, and severity indicated that residents in the urban area had already realized the health risk posed by the heat wave. Residents reported that they were concerned about the risk and perceived it as a frightening risk that could lead to serious impacts on their health. However, a low level of perceived controllability suggested that they considered it difficult to control or avoid the influence of heat waves. This contradiction reflected the demands of urban residents for ways to adapt to hot weather in the interest of their health; it also raises the policy implication that a health-protective action guide for urban residents is urgently needed to support better self-protection and adaptation to temperature anomalies. In addition, because previous studies have reported a link between public risk perception and behavioral variations to cope with climate change (Semenza et al., 2008a; Spence et al., 2011; Adger et al., 2013; Demski et al., 2017), the mediating effect of risk perception on adaptive behavior changes should be addressed.

Perceptual factors mediated the relationship between exposure and behavioral adaptation at different levels for different categories of behaviors. As indicated by the significant indirect effects and non-significant direct effect (see Table 2), the factor of heat exposure influenced residents' behavioral changes through complete mediating effects of perceived concern and severity. Higher temperatures due to climate change may cause the residents to feel subjectively that they are being harmed by exposure to heat waves, and this perception of worry may translate into a behavioral intention to increase concern about weather forecasts and health protection guidelines related to heat waves (Demski et al., 2017; Ban et al., 2017). Without the mediating effects of risk perception, exposure may not motivate the concern behaviors effectively (Fig. 1). This relationship is consistent with previous literature, which concludes that changes in concern behaviors are heavily affected by individual psychological risk perception (Ban et al.,

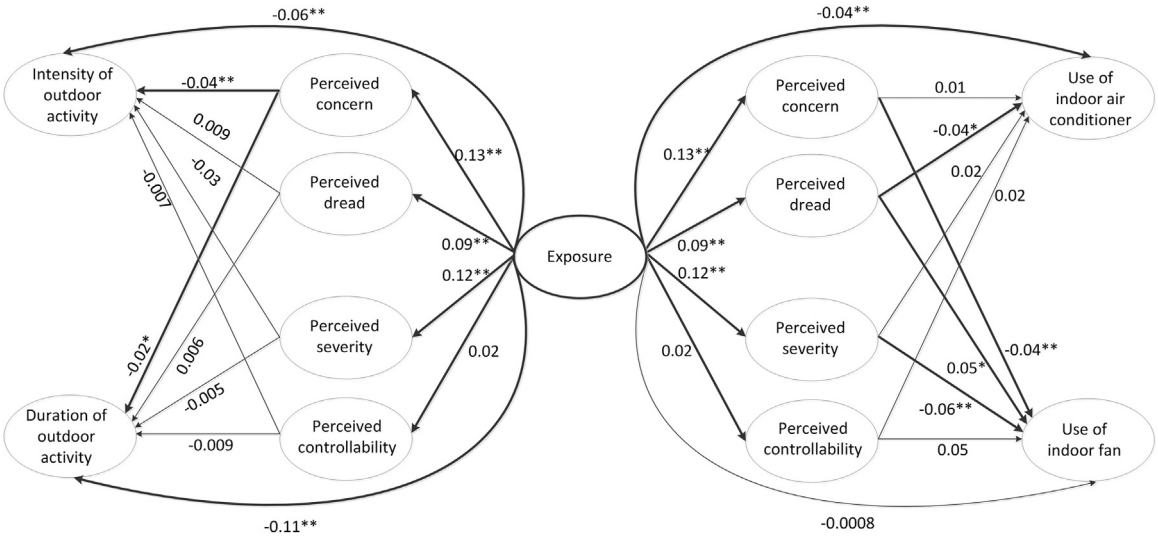

Fig. 2. Changes in on outdoor activity and indoor cooling behavior as a heat-wave adaptation mediated by public perceptions of concern, dread, severity and controllability related to heat-related health risks. Bold lines indicate significant effects (**p < 0.01, *p < 0.05).

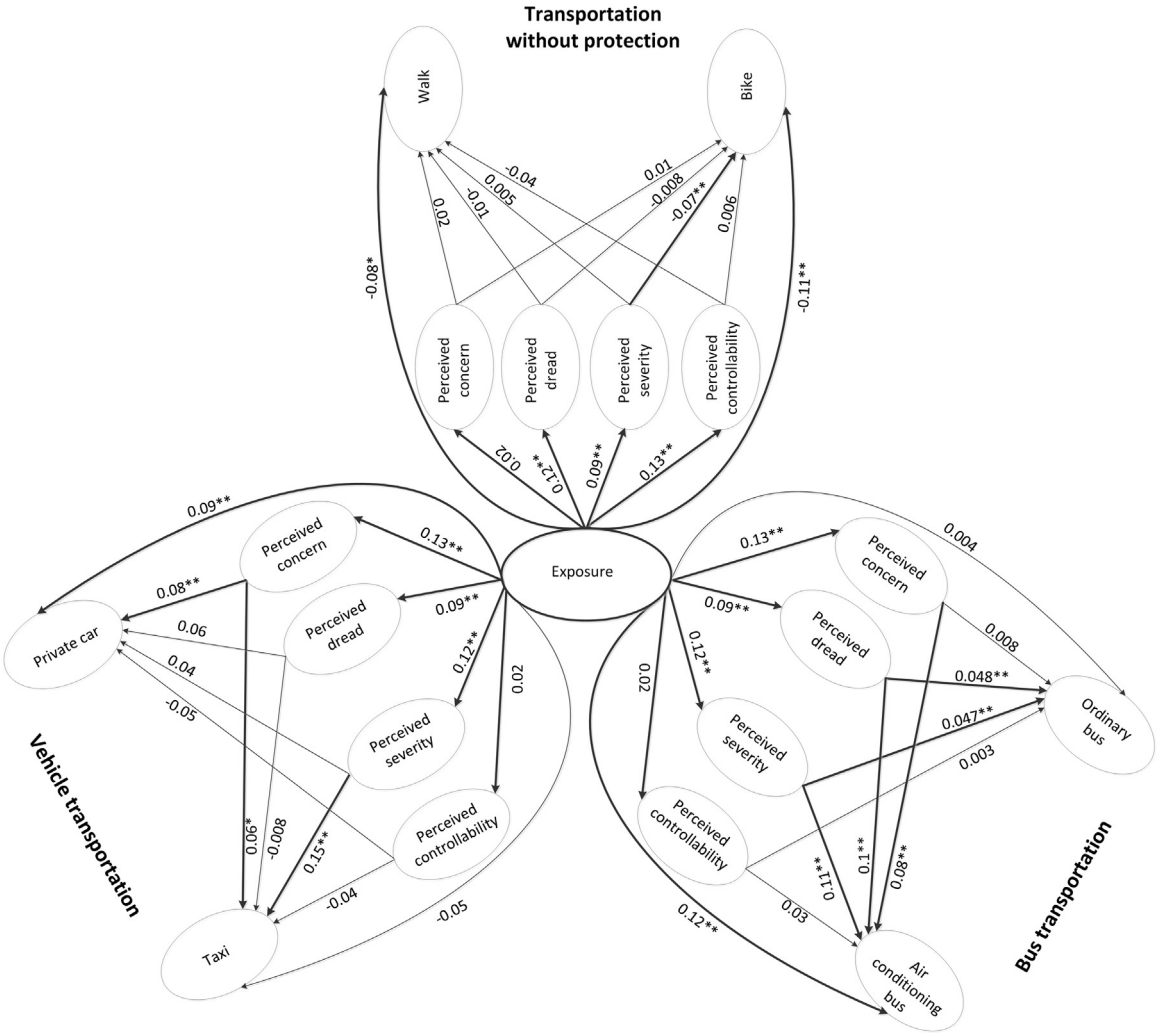

Fig. 3. Changes in transportation behavior as a heat-wave adaptation mediated by public perceptions of concern, dread, severity and controllability related to heat-related health risks. Bold lines indicate significant effects (**p < 0.01, *p < 0.05).

Table 2
Impact of temperature exposure on behavior changes to cope with heat waves and the indirect effect of perceptual factors.*

Variables	Care about the weather forecast	Care about health protection guidelines	Duration of outdoor activity	Intensity of outdoor activity	Use of indoor air condition	Use of indoor fan	Walk	Bike	Ordinary bus	Air conditioning bus	Car	Taxi
Concern	+	+	−	−	/	−	/	/	/	+	+	+
Dread	/	/	/	/	−	+	/	/	+	+	/	/
Severity	+	/	/	/	/	−	/	−	/	+	/	+
Controllability	/	/	/	/	/	/	/	/	/	/	/	/
Direct effect of X on Y	/	/	−	−	−	/	−	−	/	+	+	/

* + represented significantly positive effects; − represented significantly negative effects; / represented there were no significant effects.

2017; Ellis, 2013; Spence et al., 2011). Increasing concern behaviors is considered an important way to connect residents with messages communicating risk communication, as protective guidelines for coping with heat waves will be useless without residents' concern (Weinberger et al., 2018). As long as the residents take an interest in messages related to heat waves, they will be able to realize the potential health impact and make adaptive responses to protect themselves (Semenza et al., 2008b; Demski et al., 2017). Furthermore, as indicated by Table 1, although over 50% of residents increased their concern behaviors, 38.8% and 43.7% of the sample remained unconcerned about weather forecasts and health guidelines, respectively. These high percentages of inactive respondents must not be neglected. Thus, as part of a strategy for adapting to climate change, we suggest the importance of wide-ranging communication to increase public concern and perceptions of severity regarding heat waves and their related health risks. Behavioral intervention should be based on the dissemination of detailed knowledge about extreme heat, including what extreme heat is, how it influences health, how to adapt, and how to access guideline information. At the same time, increasing the number of residents who receive this information should also be considered critical for altering individual adaptive behaviors and increasing the effectiveness of the strategies for public health protection (McLaren and Williams, 2015), such as increasing access to early warning information (Semenza et al., 2008a).

We found that exposure to higher temperature had a stronger direct effect in terms of reducing both the duration and the intensity of outdoor activities (Fig. 2). Behavioral choices for outdoor activities were partly mediated by risk perceptions (Fig. 2 and Table 2). Residents with more perceived concern may be more likely to reduce their outdoor activities. In contrast to changes in concern behavior, residents could spontaneously adjust their outdoor behaviors to avoid exposure according to weather conditions. A similar phenomenon of individuals actively reducing direct exposure was also observed when residents were confronting heavy air pollution in a previous study (Ban et al., 2017; Cheng et al., 2017). Because avoiding direct contact with environmental hazards likely may be a natural human protective response, reducing outdoor exposure could be the easiest adaptation for laypeople to understand, the simplest for individuals to perform and the most effective way for them to adapt to hot weather (Wachinger et al., 2013). Given that more than 85% of the residents reduced their outdoor activities (Table 1) in response to clear recognition of heat-related risk in this case, we strongly recommend the dissemination of knowledge regarding the influence of heat waves on health and an action guide for reducing direct exposure as a priority in adaptive action plans and public health intervention strategies. As documented by the heat action plan implemented in France after the nationwide heat wave event of 2003 (Europe WHO 2004), the health guideline of avoiding the outdoors and taking shelter during the hottest periods of a hot day is prioritized ahead of other more professional guidelines, such as using indoor cooling systems and drinking enough water.

In contrast to the large *reduction* of outdoor activities, indoor cooling behaviors were observed to *increase* in over 85% of the residents (Table 1). The use of electric fans or air conditioners in households is a recommended adaptive option (Europe WHO). Since nearly 90% of the residents had indoor household cooling equipment in place and most of them increased their usage of electric fans or air conditioners, the studied city may already have effective defense against the negative impacts of heat waves. As reported by the statistical yearbook of household electronic equipment usage (Chinese Industrial Information Net, 2018), the number of air conditioners per 100 households in Eastern and Southern China increased to 123.7 in 2016, and the consumption rate of air conditioners increased by 27.8% in 2011. Public demand for electronic fans and air conditioners has continued to rise in recent years due to the increased occurrence of large-scale hot weather. The increased prevalence of indoor cooling equipment indicates that the ability to adapt at a regional level to climate change in China is strengthening. Therefore, we recommend that detailed guidelines for using indoor cooling systems be disseminated to the public, including suggestions for installing cooling equipment, the timing of air-conditioner use, and how to use air conditioners properly, including how to address both bodily comfort and energy conservation. When we examined the association between exposure and indoor cooling behaviors, perceptual factors were observed to have weak mediating effects on the use of air conditioning. Considering the increasing prevalence of air conditioners in China, one possible reason is that using air conditioners is currently commonly understood by the public. The behavioral decrease in the use of electric fans was mediated by increased levels of perceived severity and concern, which may indicate the possibility of residents replacing fans with air conditioners when the temperature rose sharply. Since electronic fans and air conditioners are alternatives to each other, with the latter being more effective than the former when the temperature exceeds 35 °C, an action guide should be provided to the public for correct usage of indoor cooling (WHO Regional Office for Europe, 2008).

The relationships between temperature and different modes of transportation presented interesting variations. Walk and riding bicycles, the modes that fully expose the user to the heat temperature without protection, were reduced by residents as a direct effect of increasing temperature (Fig. 3). Individuals' response in terms of transportation is similar to the way they respond in terms of outdoor activities (Table 1). Regarding bus transportation, we found that most of the residents reduced their use of ordinary buses (55.5%) while over 50% chose to increase their use of air-conditioned buses during heat waves (Table 1). Risk perception regarding heat waves significantly mediated the relationship between temperature and the behavior of taking an air-conditioned bus (Fig. 3). Residents who perceived more concern regarding heat waves and perceived them as a more serious and dreaded risk would choose air-conditioned buses as commuting transportation when the temperature increased. This pattern was not observed in the use of ordinary (non-air-conditioned) buses. Because a previous study observed that a higher degree of concern about negative impacts of climate change leads to more usage of public transportation in urban areas (Semezna et al., 2008b), an implication for adaptive strategies is proposed: on one hand, it is important to strengthen the public awareness of heat-wave-related health impacts, which may increase public behavioral intentions to take transportation that protects them from direct exposure; on the other hand, public transportation may be a priority in city infrastructure development. More accessible, efficient and diverse public transportation should be developed to ensure the convenience of residents taking public buses (Semenza et al., 2008b). Additionally, air-conditioned public transportation should be improved to shelters the public at comfortable temperatures during heat waves.

Residents did not markedly adjust their use of vehicle transportation in the way they responded to other transportation patterns. Although 51.3% of the residents increased their use of private cars, 35.7% continued in their usual patterns of car use. Taxi use was mostly unchanged (Table 1). In our previous study (Ban et al., 2017), car-driving behavior was not sensitive to the anomalies of environmental hazards and did not respond significantly to perceptual factors. The results of this study were partially similar to the previous findings. Meanwhile, significant indirect effects of perceived concern and severity of heat wave could mediate the increase in car-driving behavior (Fig. 3), which indicates that residents more aware of the negative impacts of heat waves may be more likely to use vehicles. In addition, nearly half of the residents who reduced walking and cycling also increased their use of private cars (Table S5). These results are consistent with the conclusion of Cheng's study (2017), in which public risk perception only positively impacted self-protective behaviors (actions that could benefit self-protection) but did not show a mediating effect on environmentally-friendly behaviors (actions that could directly benefit the environment but have smaller significance for self-protection). The finding of increased car driving when residents perceived heat waves as an environmental hazard suggested a shortage of behavioral interventions and a high-priority aspect to be improved in action guidelines for the residents. Driving cars to adapt to heat waves during climate change poses a contradiction between adaptation and mitigation due to the major contribution of greenhouse gases from vehicle usage to the intensification of heat. In particular, among the nations of the world, China is one of the largest sources of greenhouse gas emissions. Saving energy and reducing emissions form an important national strategy to obtain the co-benefit of mitigating climate change and air pollution (Committee of National Assessment Report on Climate Change, 2015). The high percentage of respondents in this study who did not reduce emissions under severe environmental conditions was consistent with many related studies (Blanken et al., 2001; Henry and Gordon, 2003; Semenza et al., 2008b). The urban residents' ignorance of the need to reduce car usage during heat waves indicated that they had neither been provided with proper adaptive action guides nor been effectively informed of the significance of individual actions in mitigating climate change (Blanken et al., 2001; Semenza et al., 2008b). As reported previously (Semenza et al., 2008b), the first barrier stopping residents from taking adaptive or mitigating behaviors is that they do not know how they should change their behavior. Furthermore, the perception paradox indicates that although some individuals understand the risk, they transfer the responsibility to someone else instead of taking action themselves (Wachinger et al.,

2013). Therefore, we recommended adding the concept of low-carbon living to a detailed action plan for the public and encouraging their voluntary mitigation of greenhouse-gas emissions. This measure may be an important aspect of implementing a national strategy to adapt to climate change, as mitigating climate change requires the cooperation of the whole public.

Overall, this investigation is an initial study focusing on the influence of exposure on individual behavioral adaptation in China, considering the mediating effect of personal risk perception surrounding heat waves. First, we have presented the differences in public demand for different adaptive behaviors; second, we have provided detailed suggestions for what steps should be taken and how to improve the current adaptive-action guidelines. Besides, adding daily ambient temperature as individual exposure provides an opportunity to implement targeted efforts on risk communication in responding to local temperature. Furthermore, the association between local temperature and behavioral changes will also increase the possibility of predicting public behavioral trend coping with future temperature changing, which could be supportive to make adaptive action guide during heat wave early warning. Although this cross-sectional study could not sufficiently examine the relationship among exposure, perception and health behaviors, the above two strengths make the study valuable for providing important information for identifying key indicators that influence individual behavioral adaptation and improving the design and implementation of response action plans and health interventions under climate change. The fact that only a single city was studied may limit the generalizability of the conclusion. In addition, we examined only four categories of adaptive behaviors; other individual daily behavioral changes, such as drinking water and taking shower to cool one's body, were not discussed in this study. Because spatial association is important for risk perception (Wachinger et al., 2013), rural regions are also important to consider in further studies.

5. Conclusion

In a study of the adaptive behavioral responses of 3065 urban residents to a heat wave, we provided evidence on the current state of residents' conscious adaptation and the mechanism whereby exposure and risk perception impact individual behavioral intention in a Chinese urban area. The results suggest that more targeted and detailed action guidelines are needed to improve the practicality of public adaptation according to the guidelines. Increasing awareness of heat-related health risks and providing an accessible adaptations guide are critical for the government's success in mitigating heat-related health burdens under further climate change.

CRediT authorship contribution statement

Jie Ban: Formal analysis, Methodology, Writing - original draft. **Wanying Shi:** Data curation, Formal analysis. **Liangliang Cui:** Investigation. **Chao Jiang:** Investigation. **Lianyu Han:** Investigation. **Rui Wang:** Investigation. **Tiantian Li:** Methodology, Project administration.

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Declarations of interest

None.

Ethics statement

This study was reviewed and approved by the Ethics Committee of China CDC. Written informed consent was obtained from all participants.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.envres.2019.01.006.

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